Optical Properties of Mineral Particles and Their Effect on Remote-Sensing Reflectance in Coastal Waters

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LONG-TERM GOALS

My long-term goal is to develop the base of knowledge necessary to:

(i) understand the magnitudes and variability of the ocean optical properties;

(ii) predict the inherent and apparent optical properties of the ocean including remote-sensing reflectance, given the types and concentration of suspended particles;

(iii) retrieve the inherent optical properties and concentration of seawater constituents from remote sensing.

OBJECTIVES

The primary objective of this project is to examine the optical properties of mineral particles suspended in seawater. The specific objectives for the reporting period were: (i) to conduct the laboratory experiment addressing the question of near-infrared absorption of aquatic particles; (ii) to conduct the experiments to examine the variability in the mass-specific absorption coefficient of various mineral particles, (iii) to analyze a large set of field data on light scattering in various coastal waters, and (iv) to initiate modeling efforts to examine the effect of mineral particles on ocean reflectance.

APPROACH

The accurate measurements of absorption by scattering samples such as mineral particles suspended in seawater are extremely difficult because typical absorption meters do not collect all of the scattered light. In the previous report, we described our initial efforts to measure absorption of particle suspensions with a negligible scattering error. Our method involves the use of a dual beam spectrophotometer (Perkin-Elmer Lambda 18) equipped with a 15-cm Spectralon integrating sphere (Labsphere). The particulate sample is placed inside the sphere, which allows us to detect light scattered at nearly all angles (with the exception of a small solid angle around the backward scattering angle of 180^o). As a result, our measurement is subject to a very small scattering error and provides accurate estimates of true absorption. In the reporting period, we used this method to address whether significant absorption by aquatic particles exists in the near infrared (near-IR) spectral region from

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about 700 to 850 nm. We examined four species of phytoplankton, phytodetritus derived from phytoplankton cultures, natural assemblages of mineral particles, and samples of aquatic particles from coastal and inland waters that have varying proportions of organic and inorganic particles.

With our new method for measuring absorption, we examined more than twenty samples of mineral particles, which included pure mineral species (illite, kaolinite, montmorillonite, quartz, calcite) and natural particulate assemblages from different regions (Sahara, Australia, Arctic). The dry mass of particles was measured with a micrometric balance and the elemental composition of samples was determined with inductively-coupled plasma-mass spectrometry. The particle size distribution was measured with a Coulter analyzer. The analysis of data focused on the variability in the mass-specific absorption coefficient between the various mineral samples and the identification of main elements/chromophores responsible for absorption. We also started to analyze the package effect of mineral particles associated with their particle size distribution and imaginary index of refraction.

To examine the scattering properties of particles in coastal waters, we analyzed a large data set collected during the European project Coastlooc (Coastal Surveillance Through Observation of Ocean Color) in various waters around Europe in 1997-98. The study sites included coastal waters in the Mediterranean, Adriatic Sea, English Channel, North Sea, and Baltic Sea. The scattering data were obtained from measurements with an ac-9 instrument. The analysis focused on the variability in the mass-specific scattering coefficient and interpretation of this variability in terms of variable contributions of organic and mineral particles.

Dr. Marcel Babin from France, who visited my laboratory in 2000-2001, was involved in most tasks of this study. Dr. Babin was one of the principal investigators of the Coastlooc project. Dr. Slawomir Wozniak from Poland, who has been visiting my laboratory under the NSF-NATO Postdoctoral Fellowship Program in 2001-2002, was involved in some laboratory experiments and modeling work.

WORK COMPLETED

Laboratory experiments to examine the near-IR absorption by various types of aquatic particles were completed. The paper on this subject was published (Babin and Stramski, 2002) and the results were also presented at the 2002 Ocean Sciences Meeting in Honolulu (Stramski and Babin, 2002).

Several laboratory experiments to examine the variability in the absorption coefficient by mineral particles were completed. Two extended abstracts from this work were submitted to the Ocean Optics XVI Conference (Babin and Stramski; Stramski et al., submitted). We also completed preliminary computations to examine the effects of mineral particles on ocean reflectance and the extended abstract was submitted to Ocean Optics XVI (Wozniak and Stramski, submitted).

The analysis of Coastlooc scattering data was completed and the manuscript was submitted for publication (Babin et al., submitted to L&O). Our Coastlooc absorption paper was revised, and we have been waiting for the decision from the Journal of Geophysical Research since December 2001 (Babin et al., submitted to JGR). In addition, one paper on phytoplankton optical properties, which is based on my ONR-sponsored research conducted in recent years, was published in the reporting period (Stramski et al., 2002).

RESULTS

Our measurements of absorption by various particle suspensions showed that absorption is generally negligible in the near-IR regardless of the type of particles. This result does not support previous literature data that showed significant absorption of inorganic particles in the far red and near-IR spectral region (Bukata et al., 1995). We conclude that the previous data are most likely subject to significant scattering error.

We found that the mass-specific absorption coefficient, $a_m^*(\lambda)$, varies greatly between various mineral samples. While pure mineral species such as kaolinite, montmorillonite, quartz, and calcite show virtually no absorption in the visible spectral region, the natural assemblages of mineral particles show significant and highly variable values of $a_m^*(\lambda)$, especially in the UV-blue region (Figure 1). This graph shows the spectra uncorrected for slightly negative values to illustrate the capability of our method for measuring absorption with a negligible scattering error. The variations in $a_m^*(\lambda)$ can be explained by the iron content of the mineral particles (Figure 2). Other elements showed no significant correlation with absorption. We conclude that iron is the main element responsible for significant absorption of mineral particles in the UV-blue spectral region. We also found that the package effect associated with changes in the particle size distribution produces significant variations in $a_m^*(\lambda)$. Therefore, not only the dry mass and iron content of particles but also the size distribution and imaginary index of refraction are required for adequate parameterization of mineral absorption.

Our modeling results based on Mie scattering calculations showed that the presence of mineral particles at concentrations of 1 g m^{-3} or higher may change completely the magnitude and spectral shape of ocean reflectance in comparison to clear ocean water with particle concentrations on the order of 0.01 g m^{-3} or less. To understand the influence of minerals on ocean reflectance, the particulate composition determined by the real and imaginary parts of the refractive index and the particle size distribution must be taken into account. These particle properties affect the mass-specific absorption and backscattering coefficients, which in turn produce variations in ocean reflectance at the same mass concentration of mineral particles.

Data collected during the Coastlooc project in various waters around Europe showed that the mass-specific scattering coefficient of marine particles, $b_p^*(\lambda)$, is significantly lower in coastal waters rich in minerals compared to open ocean waters where organic particles dominate. The theoretical considerations indicated that the higher $b_p^*(\lambda)$ values in organics-rich, open ocean waters are mainly due to the low apparent density of organic particles relative to their refractive index, which results from the relatively high water content of these particles.

IMPACT/APPLICATIONS

The major impact of this project is to fill the gap in our understanding of light absorption and scattering by mineral particles suspended in seawater. At present, the lack of quantitative information on the optical properties of minerals and their variability limits our capabilities to: (1) understand the magnitudes and variability of the bulk optical properties in coastal waters, (2) develop reliable remote sensing algorithms for coastal waters, (3) develop improved methods for optical imaging/detection of underwater targets and bottom objects, and (4) develop and test shallow water radiative transfer models. This project will contribute to advances in these areas of science and applications.

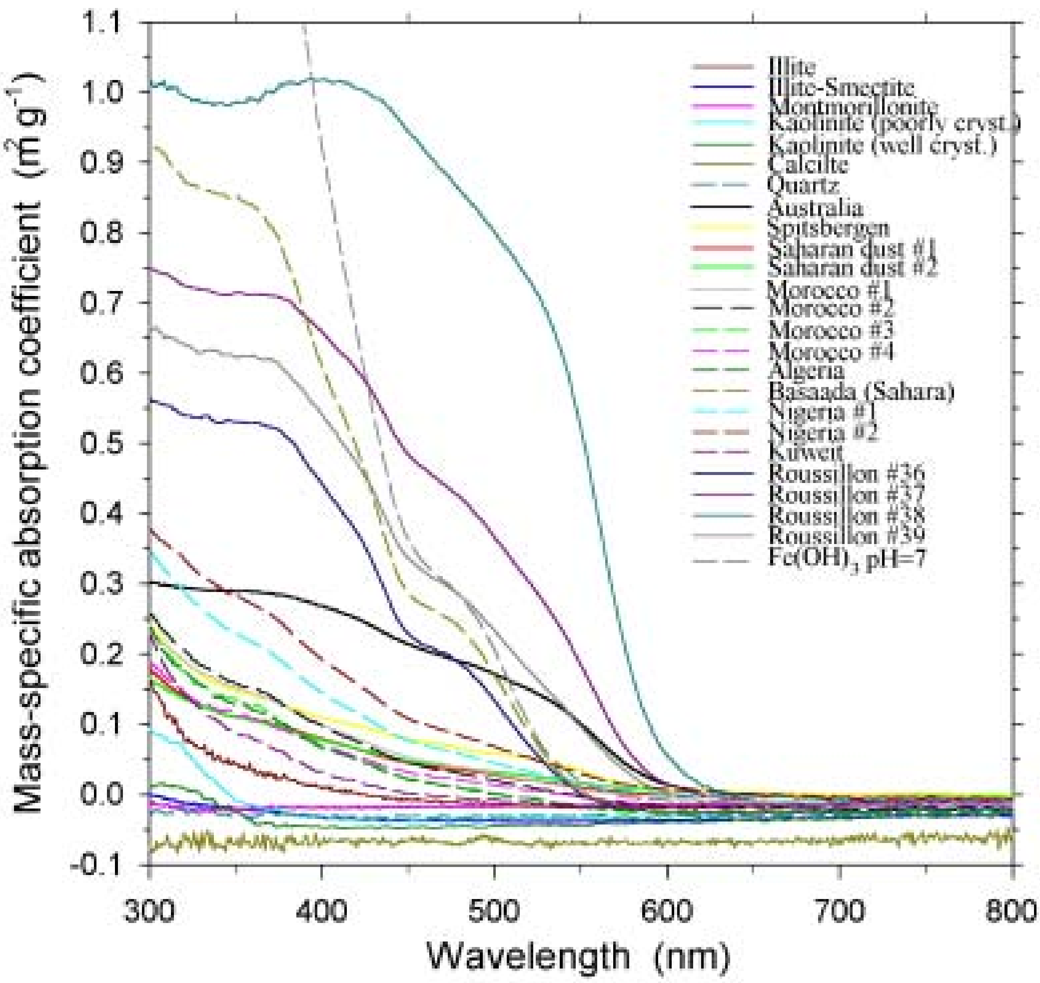

Figure 1. Spectra of the mass-specific absorption coefficient of mineral particles. [graph: absorption varies greatly between various mineral samples, especially in the UV-blue spectral region]

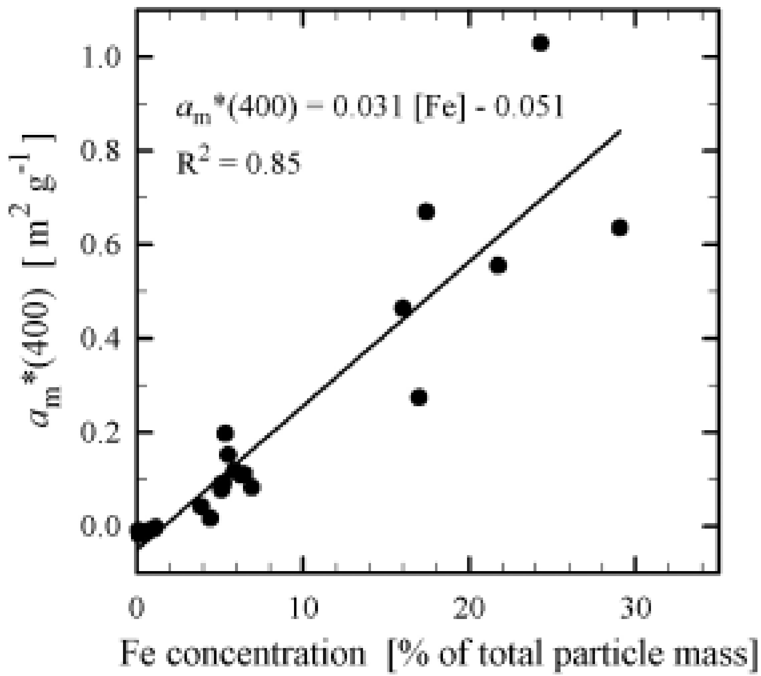

Figure 2. The mass-specific absorption coefficient of mineral particles at 400 nm as a function of iron content expressed as percent of total dry mass of particles.
[graph: absorption of mineral particles increases with an increase in iron content].

This project will also improve models relating the ocean optical properties to seawater components. In the present models, there is only one component (chlorophyll) or a few components (phytoplankton, detritus, dissolved organic matter), and a water body is considered with no regard as to a detailed composition of particulate matter, for example plankton species and mineral species. Therefore, the present models are unable to explain and predict the substantial optical variability observed in the ocean. There is a need to incorporate a more detailed description of seawater composition. The paper by Stramski et al. (2001) shows how to build such advanced optical models and this project will provide necessary information about the optical properties of various mineral particles present in seawater.

TRANSITIONS

Parts of my particle-optics database were made available to several researchers, including V. Haltrin (Naval Research Laboratory, Stennis Space Center), J. Coleman (masters thesis, University of Washington), S. Jiang (Stevens Institute of Technology, New Jersey), C. Dupouy (Universite Pierre et Marie Curie, France). The entire database have been utilized by C. Mobley (Sequoia Scientific, Inc).

RELATED PROJECTS

The European project Coastlooc (Coastal Surveillance Through Observation of Ocean Color) provided unique data on absorption and scattering properties of marine particles in various coastal waters.

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PATENTS

None